POLISH JOURNAL OF SOIL SCIENCE
VOL. XLIX/1 2016 PL ISSN 0079-2985

DOI: 10.17951/pjss/2016.49.1.91

SŁAWOMIR SMÓLCZYŃSKI*, MIROSŁAW ORZECHOWSKI*, BARBARA KALISZ*, PAWEŁ SOWIŃSKI*, PAWEŁ URBANOWICZ*

SOIL AIR-WATER PROPERTIES IN CATENA OF SEPOPOL LOWLAND

Abstract. In the sequence of soil composed of black earths, deluvial soils, organic soils covered with a thin layer of mineral-organic deposit and moorsh soils, soil texture, bulk density, content of organic carbon and organic matter, total porosity, total and readily available water as well as resources of organic matter and water in 0-25 cm and 0-100 cm layers of the soil profile were studied. A catenal variabilities of organic matter content and physical-water properties were found. Physical properties and the contents of total and readily available water depended on soil texture, organic matter content and location in a relief. Total porosity, field water capacity and volume of macropores were positively correlated with organic matter content, and negatively with bulk density. Differences in studied properties between the pedons of black earths and deluvial soils were small, whereas these differences between deluvial and moorsh soils were distinct. In the development of water resources in the profiles of these soils, presence of organic subsoil with high retention capacity played the important role. The studied soils had unfavorable distribution of soil pores, resulting from a small volume of air pores.

Keywords: glaciolimnic, colluvial, toposequence, soil pores, water retention

INTRODUCTION

The Sępopol Lowland is distinguished from Masurian Lakeland by the lithogenesis and morphogenesis. Sępopol Lowland forms an extensive basin without well-developed morainic forms and lakes. Land depressions are not very scat-

* Department of Soil Science and Land Reclamation, University of Warmia and Mazury in Olsztyn, Plac Łódzki 3, 10-727 Olsztyn

tered as in Masurian Lakeland, and slope gradient as well as erosion threat are low (Kondracki 1988). Gotkiewicz and Smołucha (1996) termed this area the zone of ice-dammed lake origin. The zone of ice-dammed lake plains includes Sepopol Lowland, formed as a result of deglaciation phase of Pomeranian Vistula Glaciation, during which clay and loam of clay facies were accumulated (glaciolimnic deposits). Associations of black earths, brown soils and lessive soils, which are intensively used in agriculture as a result of their high potential fertility, were formed from glaciolimnic deposits. Mechanical cultivation may contribute to excessive soil compaction and worsening of water retention properties, and consequently to the development of erosional processes (Nawaz et al. 2013; Paluszek 2001; Shukl and Lal 2005). In meltwater basins, which had been supplied with waters flowing on impermeable soil formations (flowing type of hydrological supply), organic soils were formed. Human activity led to the diversification of soil cover and the formation of soil toposequences comprising eroded and colluvial soils along the slope as well as upper-silted organic soils in land depressions. Brown soils and black earths were formed from these formations. They have high quality and are intensively used for agricultural purposes.

The aim of the study was to determine soil air-water properties in a typical soil sequence of black earths, colluvial soils and organic soils differently silted in surface horizons in the landscape of plains and hills of ice-dammed lakes origin in north-eastern Poland.

MATERIALS AND METHODS

Studied soils are located in southern part of Sepopol Lowland. The transect was made from the top of the slope towards the depression and 12 soil profiles were described. The slope gradient was up to 7.1 % and the soil sequence was as follows: black earths on the top, proper colluvial soils in the middle of the slope, humous colluvial soils in lower parts and at the bottom of the slope, moorsh soils, as well as slightly and strongly silted organic soils in the depression. Colluvial soils occupied the section of approximately 120 m and the thickness of colluvial deposits amounted to 118 cm. In the middle and lower parts of the slope, colluvial deposits were lying on mineral materials, whereas in the depression on organic formations. Moorsh soils were silted and had thickness of 32 cm. The land was drained with drainage pipes and the soils were used as ploughland. The soil erosion threat was low and the slope gradient was up to 7% (Fig. 4).

Soil water retention properties were determined using low- and high-pressure chambers (van Reeuwijk 2006)). Water capacities ($W_{vol.}$) were examined at the pressure of 98.1 hPa (pF 2.0), 490.5 hPa (pF 2.7), 981.0 hPa (pF 3.0) and 15 547.9 hPa (pF 4.2). On the basis of total porosity and water capacities, the amounts of following soil pores were calculated: macropores (total porosity-$W_{vol.}$ at pF 2.0), mesopores corresponding to potential useful water retention (PRU) ($W_{vol.}$ at pF 2.0 - $W_{vol.}$ at pF 4.2), effective useful water retention (ERU) ($W_{vol.}$ at pF 2.0 - $W_{vol.}$ at pF 2.7), small pores (DKR) ($W_{vol.}$ at pF 2.7 - $W_{vol.}$ at pF 4.2) and micropores $W_{vol.}$ at pF 4.2. Basing on the above, the resources of water in Ap horizon (0-25 cm) and in the horizon of 0-10 cm were calculated. Statistical calculations (mean values, standard deviation, correlation coefficients, test for significant differences) were performed using Statistica 12.0.

RESULTS AND DISCUSSION

Black earths were formed from loam, which was lying on heavy clay. The amounts of silt fraction in Ap horizon ranged from 46 % to 47 %, and the amounts of clay ranged from 20% to 25%. The content of silt and clay in colluvial soils increased down the slope. Shallow humous colluvial soils located in the depression contained 4–5 % more silt fraction and 8–16 % more clay than proper colluvial soils located in the middle part of the slope. Humus horizons of proper colluvial soils had loam texture whereas of humous colluvial soils at the bottom of the slope – clay loam texture.

In the studied catena, organic carbon content (from 23.03 g · kg^{-1} in black earths to 212.60 g · kg^{-1} in moorsh soils) and organic matter (from 39.70 g · kg^{-1} to 444.57 g · kg^{-1} respectively) (Table 1) as well as the resources of organic carbon and organic matter in humus horizons (Table 2) increased down the slope. Total porosity, field water capacity and volume of macro and micropores were significantly positively correlated with organic matter content (Table 3). Soil bulk density decreased, on average, in epipedons of studied soil sequence from 1,464 Mg m^{-3} in black earths to 0.578 Mg m^{-3} in moorsh soils, and the differences were statistically significant (Table 1). Total porosity showed a positive correlation with organic matter content, and negative correlation with bulk density (Table 3) and increased down the slope, but average differences of its value in epipedons of black earths (45.6%) and colluvial soils (46.9%) were statistically insignificant. The values of bulk density and total porosity in humus horizons of black earths were similar to the results obtained by Piaścik et al. (1998a, b) in the studies of alluvial soils at Żuławy, but in comparison to heavy soils (black earths of Kętrzyn and black earths of Gniew) studied by Kaczmarek et al. (2015) bulk density was higher, and total porosity was 10% lower.

The average water contents at pF 2.0 corresponding to field water capacity in humus horizons (Ap) of black earths (40.2%) and colluvial soils (40.3%) were similar, while in AO and Mt epipedons of moorsh soils these values were statistically significantly higher (Table 1). Similar relationships were stated for water resources at pF 2.0 in humus horizons (0-25 cm) (Table 2). However, in the 0-100 cm layer in colluvial soils water resources were almost 100 mm greater than in black earths.

Field water capacity, as well as volume of macropores were positively correlated with organic matter content, and negatively correlated with bulk density.

TABLE 1. PHYSICAL PROPERTIES OF SURFACE HORIZONS (MEAN VALUES)

Properties	Value	1Ap	2Ad	3AO	4Mt	Statistically significant differences
C [g·kg^{-1}]	X	23.03	38.52	90.66	212.60	2<3<4
	S	5.91	16.40	12.8414.16	45.96	
	CV	25.66	42.56		21.62	
Organic matter [g·kg^{-1}]	X	39.70	66.4	178.60	444.57	2<3<4
	S	10.16	28.30	22.03	83.63	
	CV	25.59	42.62	12.33	18.81	
Bulk density [Mg · m^{-3}]	X	1.464	1.292	0.791	0.578	1>2>3>4
	S	0.01	0.03	0.16	0.15	
	CV	0.68	2.32	20.23	25.95	
Total porosity [% vol.]	X	45.6	46.9	66.22	72.5	2<3,4
	S	1.91	1.64	6.70	6.19	
	CV	4.19	3.50	10.12	8.54	
pF 2.0 [% vol.]	X	40.2	40.3	55.24	58.8	1<3,4; 2<3,4
	S	2.21	0.96	6.19	5.89	
	CV	5.50	2.38	11.21	10.02	
Macrpores [% vol	X	5.4	6.4	10.9	13.8	1<3,4
	S	0.55	1.94	0.68	3.60	
	CV	10.19	30.31	6.24	26.09	
PRU [% vol.]	X	17.8	19.3	23.4	22.3	
	S	1.99	2.53	6.78	5.69	
	CV	11.18	13.11	28.97	25.52	
ERU [% vol.]	X	8.4	10.5	8.78	9.4	1<2
	S	1.22	0.61	3.7	4.2	
	CV	14.52	5.81	42.14	44.68	
RDK [% vol.]	X	9.4	8.8	14.6	12.9	2<3
	S	1.36	2.17	5.08	3.83	
	CV	14.47	24.66	34.79	29.69	
Micropores	X	22.4	21.0	25.9	37.7	3<4
	S	1.15	2.99	5.91	3.36	
	CV	5.13	14.24	22.82	8.91	
Macropores·P^{-1} [%]	X	11.8	13.9	16.0	18.1	1<3,4
	S	1.49	4.08	1.62	4.11	
	CV	12.63	29.35	10.13	22.71	
PRU·P^{-1} [%]	X	39.1	41.2	36.1	29.2	
	S	3.46	4.92	8.47	3.51	
	CV	8.85	11.94	23.46	12.02	
ERU·P^{-1} [%]	X	18.3	22.6	13.2	12.0	1<2 2>3,4
	S	1.74	1.44	3.87	3.27	
	CV	9.51	6.37	29.32	27.25	
Micropores·P^{-1} [%]	X	49.1	50.7	39.9	52.1	
	S	2.08	8.33	12.41	3.95	
	CV	4.24	16.43	31.10	7.58	

Ap – humus horizon of black earths (Gleyic Phaeozem), Ad – humus horizon of colluvial soils (Mollic Gleysols, Colluvic), AO – mineral-organic layer in Hemic Histosol, Mt – moorsh layer, X – mean, S – standard deviation, CV - coefficient of variation, The volume of macropores in studied soils was low. In epipedons of black earths and colluvial soils it amounted to, on average, 5.4% and 6.4%, respectively and in mineral-organic formations and moorshes it was 2-fold higher and the stated differences in the contents were statistically significant. A small volume of macropores which indicates a drainage porosity, on the one hand limits the access of air into the soil and plant growth, and on the other hand, impedes the infiltration of water and contributes to the development of erosion due to high soil compaction (Nawaz et al. 2013). This applies especially to black earths located on the plateau (top) and in the upper part of the slope. The proof of the severity of these processes is the occurrence of colluvial soils, occupying the longest section in a catena, and mineral-organic sediments on the surface of organic soils.

The lowest water content available for plants (PRU) was stated in epipedons of black earths, and it amounted on average to 17.8% (Table 1). In colluvial soils it was higher by

TABLE 2. PHYSICAL PROPERTIES OF STUDIED SOILS (MEAN VALUES) IN 0-25 CM AND 0-100 CM LAYERS

Properties	Value	1Ap	2Ad	3AO	4Mt	Statistically significant differences
C 25 [kg·m^{-2}]	X	7.4	12.6	18.5	31.7	1,2<4; 3<4
	S	1.78	5.15	5.16	4.84	
	CV	0.24	40.87	27.89	15.27	
Organic matter 25 [kg·m^{-2}]	X	12.8	21.6	36.8	91.9	1,2<3<4
	S	8.89	8.89	8.89	32.64	
	CV	0.69	41.16	24.16	35.52	
pF 2.0 25 [mm]	X	102.9	98.8	133.3	148.6	2<3
	S	5.51	1.71	18.92	5.44	
	CV	0.05	1.73	14.19	3.66	
pF 2.0 100 [mm]	X	383.9	470.2	610.7	591.3	1,2<3
	S	25.88	71.48	79.18	40.45	
	CV	0.07	15.20	12.97	6.84	
Macrpores 25 [mm]	X	12.7	15.4	27.0	35.3	1,2<3,4
	S	0.21	2.47	1.53	10.54	
	CV	0.02	16.04	5.67	29.86	
Macrpores100 [mm]	X	29.9	99.3	180.3	165.2	1<3
	S	2.19	49.5	53.52	81.25	
	CV	0.07	49.85	29.68	49.18	
PRU 25 [mm]	X	47.4	43.5	54.0	54.8	
	S	1.56	4.71	20.83	10.47	
	CV	0.03	10.83	38.57	19.11	
PRU 100 [mm]	X	136.0	188.4	338.4	299.7	
	S	17.54	89.33	100.02	29.06	
	CV	0.13	47.42	29.56	9.70	
ERU 25 [mm]	X	22.0	23.5	20.5	21.25	
	S	3.53	4.68	5.68	3.61	
	CV	0.16	19.91	27.71	16.99	

ERU 100 [mm]	X	65.0	139.2	135.9	107.5	1<2
	S	5.66	53.68	43.22	26.52	
	CV	0.09	38.56	31.80	24.67	
RDK 25 [mm]	X	25.4	20.0	33.5	31.6	1>2
	S	1.98	1.53	15.89	11.24	
	CV	0.08	7.65	47.43	35.57	
RDK 100 [mm]	X	71.0	98.1	202.5	181.1	2>3
	S	11.88	40.5	60.78	40.22	
	CV	0.17	41.28	30.01	22.21	
Water inaccessible to plants 25	X	55.6	52.0	73.9	95.8	1,2<3<4
	S	3.89	5.17	5.32	2.26	
	CV	0.07	9.94	7.20	2.36	
Water inaccessible to plants 100	X	251.8	245.0	426.7	643.5	2<3,4
	S	37.97	40.3	153.04	103.38	
	CV	0.15	16.45	35.87	16.07	
Total water capacity 25	X	115.6	110.9	154.7	148.6	2<3
	S	5.66	8.27	16.64	5.44	
	CV	0.05	7.46	10.76	3.66	
Total water capacity 100	X	417.6	580.9	945.2	591.3	2<3
	S	18.22	130.5	225.47	40.45	
	CV	0.04	22.47	23.85	6.84	

X – mean, S – standard deviation, CV - coefficient of variation, 25 – values in 0-25 cm layer, 100 – values in 0-100 cm layer

1.5% and in muck soils by 4-5%, but the differences were not statistically significant. The obtained values were lower than in the soils of moraine landscape (Sowiński et al. 2004; Sowinski et al. 2005), and similar to the values in the soils the Vistula Delta (Piaścik et al. 1998a, b). Within the mesopores, with the exception of colluvial soils, small pores with water inaccessible for plants prevailed (Table 1). Average values of effective useful retention (ERU) (8.4 – 10.5%) (Table. 1) were low and hardly varied between the studied soil units. The differences are distinct when compared to water resources in a 0-100 cm soil layer. In black earths mean PRU values were from 1.5 to 2.5 times, and ERU approximately 2 times lower than in colluvial and muck soils.

TABLE 3. CORRELATION COEFFICIENTS BETWEEN PHYSICAL-WATER PROPERTIES AND ORGANIC MATTER CONTENT, GRANULOMETRIC FRACTIONS IN SURFACE HORIZONS

Properties	Total porosity	pF 2.0	Macro-pores	PRU	ERU	RDK	Micropores
		% vol					
Organic matter [%]	0.861**	0.802**	0.828**	0.276	0.004	0.333	0.878**
Bulk density [$Mg \cdot m^{-3}$]	-0.987**	-0.959**	-0.842**	-0.533**	-0.039	-0.623**	-0.758**
Content of fraction							

Properties	Total porosity	pF 2.0	Macro-pores	PRU	ERU	RDK	Micropores
		% vol					
1-0.1	0.341	0.226	0.535*	0.327	0.174	0.450	0.014
0.1-0.02	-0.293	-0.258	-0.313	-0.194	-0.143	-0.198	-0.247
0.02-0.002	-0.429	-0.519	-0.139	-0.151	-0.271	0.124	-0.761**
< 0.002	0.231	0.383	-0.163	0.030	0.208	-0.292	0.655**
<0.02	-0.022	0.137	-0.381	-0.091	0.080	-0.347	0.353

* - significance level at α= 0.05. ** - significance level at α= 0.01

The average volumes of micropores in black earths and colluvial soils were similar and amounted to 22.4% and 21.0%, respectively, while in AO epipedons, it increased to 25.9% and in Mt epipedons to 37% by volume. The pedons of moorsh soils either in 0- 25 cm or 0-100 cm layer contained significantly higher amounts of water not available to plants than colluvial soils (Table 2).

Generally it can be said that air-water and retention soil properties of the studied catena are determined mainly by granulometric composition and organic matter content, which was also confirmed by the studies of soil catenas in moraine and delta landscapes (Orzechowski, Smólczyński 2010; Piaścik et al. 1998a; Sowiński et al. 2004). Translocation of clay fraction from the top of the slopes and its accumulation in lowermost located shallow colluvial soils and organic soils increases the retention of fine capillaries and water inaccessible to plants (micropores), thereby lowers total porosity as well as potential and effective useful retention (PRU and ERU) in relation to not silted moorsh soils (Smólczyński 2009; Sowiński et al. 2005). Differentiation of soil properties in the studied catena stems from the variability of pedons along the slope. The variability of soil cover is a consequence of agricultural use of soils. As a result of years of research, however, there was no statistically significant effect of different tillage systems of heavy soils on their ability to store water, including capillary and maximum water capacity (Kotorová, Mati 2008).

TABLE 4. CORRELATION COEFFICIENTS BETWEEN PHYSICAL-WATER PROPERTIES [MM] AND ORGANIC MATTER CONTENT, [KG·M^{-2}] IN 0-25 CM LAYER

Properties	Total porosity 25	pF 2.0 25	Macro-Pores 25	PRU 25	ERU 25	DKR 25	Micro-Pores 25
Organic matter 25 [kg·m^{-2}]	0.716*	0.782*	0.657*	0.319	-0.200	0.352	0.857*

* - significance level at α= 0.05. ** - significance level at α= 0.01

Distribution of soil pores in studied catena was unfavorable. The share of macropores in relation to total porosity ranged from 11.8% to 18.1%. According to Olness et al. (1998) optimal balance between the ability to retain water and aeration is maintained when the sum of mesopores and micropores volume amounts to 66% of total porosity and the capacity of air amounts to 34%. Soil pore distribution was determined mainly by the density and content of organic matter and mineral fraction as indicated by the calculated correlation coefficients.

The study has shown that type and retention abilities of deeper layers of a soil profile play crucial role in the development of water resources in pedons, which was also stated in the studies of moraine landscape in Mazurian Lakeland (Smólczyński, Orzechowski 2010).

In the studied toposequence, as opposed to soils with a lighter texture in moraine landscape, little variation of studied physical-water properties between black earths and colluvial soils were stated. Differences in the properties occur between moorsh soils and colluvial soils.

CONCLUSIONS

1. Physical properties as well as contents of total and readily available water depended on soil texture, organic matter content and location in a relief. Total porosity, field water capacity and volume of macropores were positively correlated with organic matter content and negatively correlated with bulk density.
2. Studied soils had unfavourable pore distribution resulting from low volume of air pores.
3. Differences in studied properties between the pedons of black earths and colluvial soils were small, whereas these differences between colluvial and moorsh soils were distinct.

REFERENCES

[1] Gotkiewicz J., Smołucha J., 1996. *Characteristics of young glacial landscapes of the Masurian Lake District (in Polish)*. Zesz. Probl. Post. Nauk Roln., 431: 119–136.
[2] Kaczmarek Z., Gajewski P., Mocek A., Owczarzak W., Glina B., 2015. *Physical and water properties of selected Polish heavy soils of various origins.* Soil Science Annual, 66, 4: 191–197.
[3] Kondracki J., 1988. *Physical geography of Poland (in Polish)*. PWN, Warszawa.
[4] Kotorová D., Mati R., 2008. *The trend analyse of water storage and physical properties in profile of heavy soils*. Agriculture (poľnohospodárstvo), 54, 4: 155–164.
[5] Nawaz M.F., Bourrie G., Trolard F., 2013. *Soil compaction impact and modelling*. Agron. Sustain. Dev., 33: 291–309.
[6] Olness A., Cl App C.E., Liu R., Palazzo A.J., 1998. *Biosolids and their effects on soil study on Alfisols in West Central Ohio*. Soil Sci., 170: 445–456.

[7] Orzechowski M., Smólczyński S., 2010. *Air-water properties of alluvial and deluvial soils in various landscapes of north-eastern Poland*. Pol. J. of Soil Science, 43, 2: 103–115.

[8] Paluszek J., 2001. *Water-air properties of eroded lessivés soils developed from loess (in Polish)*. Acta Agrophysica 56: 233–245.

[9] Paluszek J., 2011. *Criteria of evaluation of physical quality of Polish arable soils (in Polish)*. Acta Agrophysica, 191, 2: 1–138.

[10] Piaścik H., Orzechowski M., Smólczyński S., 1998a. *Air, water and retaining properties of alluvial soils in delta landscape*. Pol. J. of Soil Science. 31, 2: 1–7.

[11] Piaścik H., Smólczyński S., Orzechowski M., 1998b. *Physical, water and retaining properties of hydrogenic solis of the Vistula Delta*. Pol. J. of Soil Science. 31, 2: 9–14.

[12] Shukl A M.K., Lal R., 2005. *Erosional effects on soil physical properties in an on-farm study on alfisols in west central Ohio*. Soil Science, 170: 445–456.

[13] Smólczyński S., Orzechowski M. 2010., *Soils of ecotone zones of meltwater basins and slopes in a youn glacial landscapes of the Mazurian Lakeland (in Polish)*. Soil Science Annual, 61, 4: 217–226.

[14] Sowiński P., Smólczyński S., Orzechowski M., 2004. *Effect of agricultural land use on physical and water properties of soil in a ground moraine of the Mazurian Lakeland (in Polish)*. Annales UMCS, Sec. E, 59, 3: 1057–1064.

[15] Sowiński P., Smólczyński S., Orzechowski M. 2005., *Air, water and retaining proprties of soils of the midmorainal depressions in the landscape of Olsztyn Lakeland (in Polish)*. Zesz. Probl. Post. Nauk Roln., 506: 425–432.

[16] van Reeuwijk L. P. 2006. *Procedures for soil analysis.* 7th Edition. Technical Raport 9, ISRIC – World Soil Information, Wageningen, Netherlands.